# Search for Single Top Quark Production at the Tevatron

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**Abstract.** We report on a search for single top quark production using data taken during Run II of the Fermilab Tevatron collider in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The standard model predicts two main modes of single top quark production: the s-channel decay of a virtual W boson and the t-channel exchange of a W boson. We set upper limits on the cross sections for these two processes.

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In $p\bar{p}$ collisions, top quarks are predominantly produced in pairs via the strong interaction ($q\bar{q} \rightarrow g \rightarrow t\bar{t}$). The standard model also allows production of single top quark through the electroweak *Wtb* vertex. Consequently, measurement of single top quark production enables one to constrain the magnitude of the CKM matrix element $V_{tb}$ and to study the properties of the *Wtb* coupling. Single top quark is primarily produced in the *s*- and *t*-channel shown in Fig. 1.

Single top production has never been observed [1-5] so far due to a smaller cross section and much higher background from other physics processes. In the following, we present an update on the searches for single top quark production by the CDF and DØ collaborations.



**FIGURE 1.** The dominant Feynman diagrams for single top quark production at the Tevatron: s-channel, tb final state (left diagram), and t-channel, tqb final state (right diagram).

As the top quark predominantly decays into a *b* quark and a *W* boson, the final state signature consists of two (*s*-channel or *tb*) or three (*t*-channel or *tqb*) quarks and a *W* boson. The latter is required to decay leptonically ($W \rightarrow e\nu, \mu\nu$) to reduce background from QCD multi-quark production processes. Thus, the signal signature consists of a high transverse energy lepton, missing transverse energy due to the

unreconstructed neutrino, and two (*tb*) or three (*tqb*) jets. The largest backgrounds with a similar topology are from the associated production of a *W* boson with jets (*W*+jets) and $t\bar{t}$ production.

The CDF and DØ collaborations use data with integrated luminosity of $(162 \pm 10)$ pb$^{-1}$ and $(366 \pm 24)$ pb$^{-1}$, respectively for their analyses. To select data samples, both collaborations use standard lepton, missing transverse energy, and jet reconstruction algorithms described in detail elsewhere [4, 5]. To estimate selection efficiencies both collaborations simulate single top quark production using leading order generators CDF uses MadEvent [6], while DØ uses a modified version of CompHEP [7]. To simulate background processes both collaborations use ALPGEN [8] generators that incorporate hard interaction matrix element calculations at leading order. These generators were then interfaced to HERWIG [9] (CDF) and PYTHIA [10] (DØ) in order to reproduce the next-to-leading order kinematic distributions of the decay particles. Monte Carlo samples are processed with the full GEANT [11] simulations of the CDF and DØ detectors and passed through the event reconstruction programs.

After selection criteria are applied, CDF observes 42 events compared to estimated $4.3 \pm 0.5$ signal and $33.8 \pm 5.9$ background events, respectively. To extract the signal from the data, the CDF uses sensitive kinematic variables that are compared in data and Monte Carlo simulation samples via a likelihood method. To extract the combined *s*- plus *t*-channel signal in data, the CDF utilizes the scalar sum of missing transverse energy and the transverse energies of the lepton and all the jets in the event. Similarly, to extract the *t*-channel signal in data, another sensitive kinematic variable is used: a product of the charge of a lepton and the pseudorapidity of the light quark jet. No significant evidence for electroweak single top quark production is found, and the upper limits at the 95% confidence level (C.L.) are summarized in Table 1.

TABLE 1.  Upper limits at the 95% C.L. of single top cross sections in pb (CDF).

|  | s-channel | t-channel | Combined |
|---|---|---|---|
| Expected limit | 12.1 | 11.2 | 13.6 |
| Observed limit | 13.6 | 10.1 | 17.8 |

The DØ collaboration observes 229 events in the electron *W* boson decay mode and 138 events in the muon decay mode with estimated $10.2 \pm 1.4$ and $9.2 \pm 1.4$ signal events and $213.6 \pm 20.7$ and $159.3 \pm 17.6$ background events, for the respective modes. The number of observed events is consistent with the background prediction within uncertainties. Upper limits at 95% C.L. are set on the single top quark production cross sections using a Bayesian approach [12]. To extract these limits, two likelihood discriminant filters were designed to distinguish signal from two main backgrounds ($t\bar{t}$ and *W*+jets). These filters use kinematic observables including transverse momenta, invariant masses, and angular variables of the decay particles. DØ assume a Poisson distribution for the observed counts, and a flat prior probability for the signal cross section. The priors for the signal acceptance and the backgrounds are multivariate Gaussians centered on their estimates and described by a covariance error matrix taking into account correlations across the different sources and bins. Plots for the Bayesian posterior density are provided in Figure 2. The observed

(expected) limits at 95% C.L. are 5.0 pb (3.3 pb) for the s-channel and 4.4 pb (4.3 pb) for the t-channel.

The CDF and DØ collaborations analyzed 162 pb$^{-1}$ and 370 pb$^{-1}$ of data, respectively, and find no evidence for single top quark production. Upper limits at the 95% C.L. have been set on the single top quark cross section; and the best limits are 5.0 pb for *s*-channel production and 4.4 pb for *t*-channel production (DØ). As the theoretical predictions [13] for the single top quark production cross sections are 0.9 pb for *s*-channel and 2 pb for *t*-channel, it may take several inverse femtobarn of data to observe standard model production of single top quarks at the Tevatron. However, if the analysis methods are improved by reducing systematics and improving the reconstruction techniques, the discovery of electroweak top quark production can be attained with a smaller data sample.
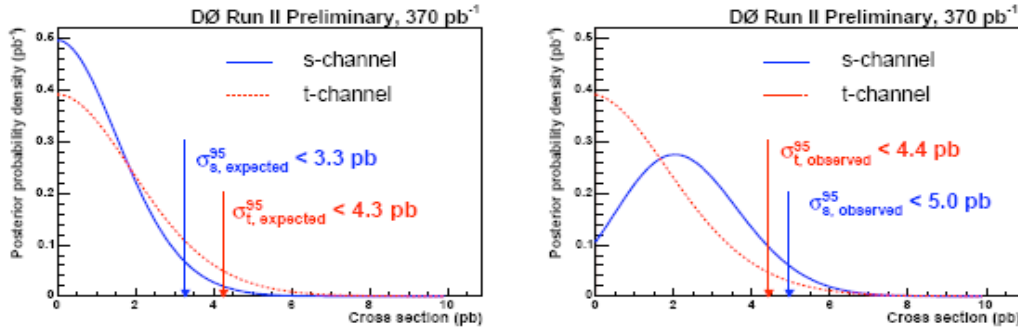


**FIGURE 2.** Expected (left) and observed (right) Bayesian posterior densities with 95% C.L. limits for DØ analysis.

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